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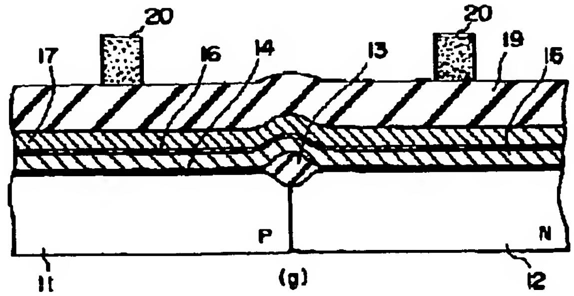

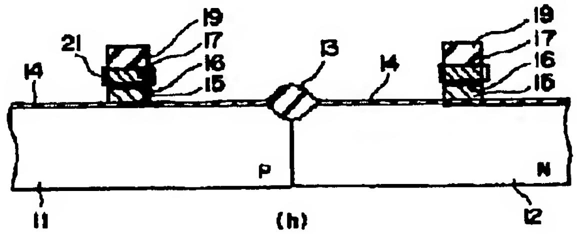

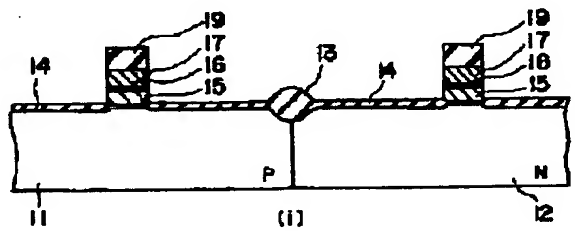

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TITLE : MANUFACTURE OF SEMICONDUCTOR DEVICE

ABSTRACT : PROBLEM TO BE SOLVED: To obtain a semiconductor device which restrains changes in the shape of a gate electrode, composed of a high-melting-point metal.

SOLUTION: Immediately after a spontaneous oxide film 21 has been removed by a reduction operation, an oxidation treatment at 800°C and for about 60 minutes is executed in an atmosphere which contains N_2, H_2 and H_2O. For example, an H_2 partial pressure is set at 2.5×10^{-2} Torr, and an H_2O partial pressure is set at 2.5×10^{-3} Torr. At this time, the vapor pressure of W oxo-acid can be suppressed, and the evaporation amount of a W (tungsten) film 17 can be suppressed to 1 nm or lower. In addition, by selective oxidation treatment, the bottom end part of a gate electrode is oxidized, and a thick oxide film in a bird's beak-shape is formed. As a result, the corner at the bottom end part of a polycrystalline silicon film becomes a rounded shape, the concentration of an electric field in the bottom end part of the gate electrode is relaxed, and the reliability and the characteristic of an element are enhanced.

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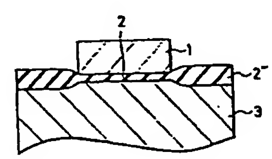
(54) **Method for producing a semiconductor device comprising an oxidation step.**

(57) A silicon wafer (3) having a tungsten and/or molybdenum film (1) formed in its surface is heat-treated in hydrogen containing vapor. Thus, silicon can be selectively oxidized (2) without substantially oxidizing the tungsten and/or molybdenum film (1).

FIG. 7b



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TITLE MODIFIED
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METHOD OF PRODUCING SEMICONDUCTOR DEVICE

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to a method of producing a semiconductor device and more particularly, to a method of producing a semiconductor device equipped with electrodes and interconnections consisting of tungsten, molybdenum or their silicides.

Description of the Prior Art

As is known well in the art, polycrystalline silicon has been used widely as a material for electrodes and interconnections of a conventional semiconductor device.

Polycrystalline silicon has been used for the following reasons. In order to miniaturize an MIS transistor, it is inevitable to employ so-called "self-alignment" techniques which form source and drain by ion implantation using the gate electrode as the mask. After ion-implantation is completed, however, annealing at high temperatures must be made by all means to remove distortion of the source and drain region that has developed due to ion-implantation.

Accordingly, to produce a miniature MOS transistor by self-alignment, the gate electrode must be made of a material which can withstand the heat-treatment at high temperatures, and polycrystalline silicon having a high melting point has replaced aluminum that was used widely and previously.

The disadvantage of this polycrystalline silicon is, however, that its electric resistance is greater than metals. Since higher integration and miniaturization of semiconductor devices has made a rapid progress in recent years, the width of the electrode or interconnection becomes extremely small. Accordingly, if polycrystalline silicon is used, the resistance of the electrode or interconnection does not become sufficiently low and it is difficult to produce a miniature semiconductor device having high characteristics.

To solve this problem, the use of tungsten, molybdenum or their silicides has been proposed in place of polycrystalline silicon so as to form the electrode and the interconnection. Since tungsten, molybdenum or their silicides have a high melting point, they can withstand annealing at high temperatures and moreover, since their electric resistance is by far lower than that of polycrystalline

silicon, the problem described above, that occurs when polycrystalline silicon is used, does not develop even when the width of the electrode or interconnection is extremely small.

However, tungsten and molybdenum have the problem that they are more easily oxidized than silicon. When heat-treatment is carried out at about 300°C or above in an oxidizing atmosphere, therefore, they are rapidly oxidized, disclosed or peel off from the substrate.

An insulating film (SiO_2 film) deposited on a semiconductor substrate is damaged or contaminated if an insulating film becomes thin or ion-implantation is effected using the gate as the mask to form the source and drain during the fabrication of an MOS transistor. Accordingly, the damaged or contaminated insulating film must be removed by etching after completion of gate formation and ion-implantation and the heat-treatment is carried out in an oxidizing atmosphere to re-grow an SiO_2 film on the semiconductor substrate. This process is carried out generally and widely and is an indispensable step to form a high reliability MOS transistor. (This process or treatment will be hereinafter referred to as "light oxidation").

When polycrystalline silicon is used as the gate electrode and the interconnection, light oxidation described above can be carried out smoothly without any problem but since tungsten and molybdenum are extremely oxidizable as described earlier, the gate electrode and the interconnection are extremely easily oxidized when tungsten or molybdenum is used as the material, so that semiconductor devices having high reliability and high integration density can not be produced.

SUMMARY OF THE INVENTION

To eliminate the problems with the prior art described above, the present invention is directed to provide a method of producing a semiconductor device by which one can form the semiconductor device having the electrode and interconnection consisting of tungsten, molybdenum or their silicides without any problem.

It is another object of the present invention to provide a method of producing a semiconductor device which method can selectively oxidize silicon alone without substantially oxidizing tungsten, molybdenum or their silicides.

To accomplish the objects described above, the present invention selectively oxidizes silicon alone

without substantially oxidizing tungsten, molybdenum or their silicides by carrying out heat-treatment in a mixed atmosphere of hydrogen and vapor.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram showing the preferred ranges of vapor-hydrogen partial pressure ratio and heating temperature;

Figure 2 is a diagram showing the relation between the water temperature of a bubbler and the partial pressure ratio in the resulting hydrogen;

Figure 3 is a diagram showing the relation between the partial pressure ratio in hydrogen and the thickness of the resulting SiO_2 film;

Figures 4 and 5 are diagrams showing the relation between the thickness of the resulting SiO_2 film and the heating time and between the thickness of the SiO_2 film and the heating temperature, respectively; and

Figures 6 through 11 are process diagrams showing other embodiments of the present invention, respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As is well known, Si and most metals form their oxides upon reacting with vapor.

According to the examination carried out by the inventor of the present invention, however, it has been found that only Si can be selectively oxidized

without the oxidation of W and/or Mo by heating Si and W and/or Mo in a mixed atmosphere consisting of the vapor and hydrogen.

Though the mechanism of this reaction has not been clarified fully, it is assumed that even if W and Mo are oxidized by the vapor to their oxides, the resulting oxides are immediately reduced to the metallic state by the coexisting hydrogen, whereas Si is not reduced by hydrogen but remains as-oxidized by the vapor.

It has also been found out that the selective reduction of W and Mo is significantly affected by the partial pressure ratio P_{H_2O}/P_{H_2} (which will be hereinafter represented by R).

In other words, the relation represented by curves a, b and c in Figure 1 has been found existing between the partial pressure ratio R_c, when the reduction of W, Mo and Si oxides starts, and various temperatures.

As can be seen clearly from Figure 1, all of W, Mo and Si are reduced in the region below the curve c representing the reduction of SiO_2 but if the heat-treatment is carried out inside the region between the curve representing the reduction of WO_3 and the curve c described above, only Si can be selectively

oxidized without substantially oxidizing W.

Similarly, only Si can be oxidized selectively without substantially oxidizing W and Mo if the heat-treatment is carried out in the region interposed between the curve b representing the reduction of MoO_2 and the curve c described above.

When the heat-treating temperature is 1,000°C, for example, only Si can be selectively oxidized without oxidizing W and Mo (with the oxides being reduced), if R is in the range of from 10^{-6} to about 1.

If the present invention is applied to the "light oxidation" when fabricating MOS transistors, for example, the SiO_2 film can be formed on the Si substrate without oxidizing the electrodes and interconnections made of W, Mo or their slicides, and the present invention is extremely advantageous for the fabrication of the MOS transistors having high integration density.

If the heat-treating temperature is below about 400°C, however, the oxidation speed of Si becomes extremely slow and when it is above about 1,200°C, on the other hand, deformation of the diffusion region formed in the substrate becomes so remarkable and damage of the reaction tube becomes also great. For these reasons, the heat-treating temperature is selected

in the range of from about 400 to about 1,200°C.

Example 1

After an SiO_2 film was formed on a silicon wafer by a known thermal oxidation process, a 0.3 μm-thick W or Mo film was formed by sputtering on the SiO_2 film and was then heat-treated at 1,000°C for 30 minutes in an N_2 or Ar atmosphere containing 1 ppm of oxygen as an impurity.

According to the procedures described above, the W and Mo films were not mostly oxidized but there were also the cases in which only the film edge portions were oxidized or the entire surface of the film was oxidized, so that a stable result could not be obtained. Incidentally, the Si surface was oxidized in all cases.

Next, the sample described above was heated at 1,000°C for 30 minutes in the hydrogen/vapor atmosphere in which the partial pressure ratio R of vapor to hydrogen was changed stepwise from 1, 2×10^{-1}, 3×10^{-2}, ..., 1×10^{-6} so as to examine the state of oxidation of W, Mo and Si. As a result, oxidation of W and Mo was observed when R was 1 but could not be observed when R was below 3×10^{-1}. On the other hand, Si was oxidized in all cases. Here, the state of oxidation was examined by X-ray photoelectronic spectrometry.

Table 1

vapor / material	H_2/H_2O					N_2	A_r
	R (partial pressure ratio of H_2/H_2O)					O_2 · 1 ppm	
	1	$3x10^{-1}$	$3x10^{-2}$	$1x10^{-4}$	$1x10^{-6}$		
Si	X	X	X	X	X	X	X
W	X	O	O	O	O	X	X
Mo	X		O		O	X	X

Remarks: X .... oxidized

O .... not oxidized

Example 2

This example illustrates the relation between the oxidation of Si and the partial pressure ratio R (P_{H_2O}/P_{H_2}) of H_2O and H_2 in the atmosphere when heating is effected in the H_2/H_2O atmosphere.

The vapor-containing hydrogen could be obtained by passing hydrogen through a bubbler containing pure water, and the vapor quantity in hydrogen could be adjusted to a desired value by changing the temperature of the pure water in the bubbler.

Thus, heat-treatment was carried out at 950°C for 10 minutes by changing the ratio R (P_{H_2O}/P_{H_2}) and the thickness of the SiO_2 film formed on the silicon

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wafer was measured using an ellipsometer.

The silicon wafer used for the measurement was washed by hydrofluoric acid before heating to remove in advance the oxide film on the wafer surface. The result obtained was shown in Figure 3. The thickness of the SiO_2 film increased substantially proportionally to the value R within the range of $0 < R \leq 0.4$. Figure 4 shows the result of the measurement of time dependence of the thickness of the SiO_2 film when the heating temperature was 1,000°C and R was 0.05. Similarly, Figure 5 shows the dependence of the thickness of the SiO_2 film upon the heating temperature when R was 0.05.

Example 3

This example illustrates the application of the present invention to the fabrication of an MOS field effect transistor.

First, as shown in Figure 6a, a tungsten film 1 and a silicon dioxide film 2' were formed sequentially in thickness of 350 nm and 60 nm, respectively, on a 20 nm-thick silicon dioxide film 2 that was formed on the surface of a silicon substrate 3. The silicon dioxide film 2' and the tungsten film 1 were then patterned sequentially into the pattern of a gate electrode by known dry etching techniques. Next, an

impurity ion was implanted into the silicon substrate 3 through the silicon dioxide film 2 using the electrode consisting of the silicon dioxide film 2' and the tungsten film 1 as the mask, to form a source and drain 4 as shown in Figure 6b. The silicon oxide films 2, 2' at the portions other than the portion covered with the W film 1 were selectively removed using a hydrofluoric acid solution diluted to 1/10 by water, as shown in Figure 6c.

Next, the heat-treatment was effected at 900°C for 15 minutes in hydrogen containing 5% of vapor to grow an about 10 nm-thick silicon dioxide film 2" on the exposed silicon substrate 3 as shown in Figure 6d. Thereafter, a phosphoglass layer 5 was deposited in a thickness of about 500 nm over the entire surface and contact holes were bored by photoetching. Aluminum interconnections 6 were formed to complete the MOS transistor as shown in Figure 6e.

This example corresponds to the light oxidation step in the silicon gate process, and the tungsten gate transistor produced by this step exhibited the improvement in the MOS characteristics (break-down voltage of the SiO_2 film and variance of breakdown voltage).

Example 4

A 350 nm-thick tungsten film 1 was deposited and patterned on a 20 nm-thick SiO_2 film 2 that was formed on a Si single crystal substrate 3 as shown in Figure 7a. Heat-treatment was effected at 1,000°C for one hour in hydrogen passed through a bubbler of pure water (containing about 3% of water), whereby the thickness d_1 of the SiO_2 film 2 of the portion covered with the tungsten film 1 and the thickness d_2 at the portion not covered with the tungsten film 1 increased to 30 nm and 70 nm, respectively. However, the tungsten fim 1 was not oxidized. The moisture content in hydrogen, heating temperature and heating time were increased (or decreased) in accordance with Example 2 and the thickness d_1 and d_2 of the SiO_2 film increased (or decreased) in response to the former. After the heat-treatment, the breakdown voltage of the SiO_2 film was measured using the tungsten film as the electrode. The breakdown voltage was found increased than before the heat-treatment. It was thus confirmed that the present invention could effectively prevent degradation of the characteristics of the SiO_2 film due to the heat-treatment.

Example 5

A 300 nm-thick tungsten film 1 was vacuum deposited on a 20 nm-thick SiO_2 film 2 that was formed on an Si crystal substrate 3 as shown in Figure 8a, and an 80 nm-thick SiO_2 film 2' was deposited by CVD on the tungsten film 1. Unnecessary portions were removed by sequentially etching the SiO_2 film 2' and the tungsten film 1. The sample was then heated at 900 to 1,000°C for 15 minutes in hydrogen containing 3 to 20% of water, whereby the portion of the SiO_2 film 2"' not covered with the tungsten film 1 became thicker in the same way as in Example 4 but the thickness of the SiO_2 film 2 below the tungsten film 1 remained substantially unaltered, as shown in Figure 8b. As can be understood from this Example, when those materials (at least one of polycrystalline Si, PSG, SiO_2, Si_3N_4 and the like) which are generally used as a mask for the diffusion of an impurity are used for the heat-treatment on the tungsten film, the function of the mask for the prevention of oxidation can be more improved than when heat-treatment is carried out using the tungsten film alone.

Example 6

A 350 nm-thick molybdenum film 8 was vacuum deposited on a polycrystalline silicon substrate 7 as

shown in Figure 9a and unnecessary portions were removed by etching the film 8. The sample was heat-treated at 900°C for 30 minutes in hydrogen containing 5% of vapor. As a result, the molybdenum film 8 reacted with the polycrystalline silicon substrate 7 and a molybdenum silicide layer 9 was formed at their contact portion. On the other hand, the portion of the surface of the polycrystalline silicon substrate 7 at which the molybdenum film 8 did not exist and which was exposed was oxidized to form a thick SiO_2 film 2. According to this method, contact could be established between the molybdenum film and the polycrystalline silicon substrate and at the same time, an insulating film could be formed on the polycrystalline silicon in self-alignment with the molybdenum electrode. Substantially the same result could be obtained by use of a tungsten film in place of the molybdenum film.

Example 7

Figures 10a through 10c illustrate another method of producing an MOS field effect semiconductor device to which the present invention is applied.

First, as shown in Figure 10a, an about 350 nm-thick tungsten film was formed on a 20 nm-thick field insulating film (SiO_2 film) 2 (reference numeral 2"'

represents a field silicon diode film formed in advance) that was formed on the surface of an Si crystal substrate 3. The tungsten film was then patterned to form a gate electrode 1. Next, the sample was heated in an oxygen atmosphere of about 400°C to form an about 50 nm-thick tungsten oxide film 10 on the surface of the tungsten film 1 as shown in Figure 10b. Using the tungsten oxide film 10 and the tungsten film 1 as the mask, an impurity was doped to the surface region of the Si substrate 3 and the sample was heat-treated at 950°C for 30 minutes in hydrogen containing 5% of vapor, thereby forming source and drain region 4. In this process, the tungsten oxide film 10 on the surface of the tungsten film 1 served as the mask for doping the impurity by ion implantation or the like, and was reduced to tungsten due to the subsequent heat-treatment in the H_2O-H_2 atmosphere, as shown in Figure 10c. Due to the heat-treatment described above, the silicon oxide film on the source-drain region 4 became thicker than the oxide film below the gate electrode.

Example 8

An about 250 nm-thick molybdenum silicide film 9 was formed on the surface of a 300 nm-thick poly-

crystalline silicon plate 7 as shown in Figure 11a and a molybdenum film 8 was vacuum deposited on it in a thickness of about 300 nm. Unnecessary portions were removed by etching to form an electrode 8. The sample was heated at 900°C for 10 minutes in hydrogen containing 5% of water, whereby a part of the molybdenum electrode 8 was converted to its silicide, and an SiO_2 film 2 was formed on the exposed surface of the resulting molybdenum silicide film 9. The reason was assumed to the fact that the portion below the molybdenum electrode was converted to the silicide due to the supply of Si from the polycrystalline silicon film 7 as the base to the molybdenum silicide film 9 and the SiO_2 film could be formed at the exposed portion of the molybdenum silicide film. As can be understood clearly from this example, the present invention makes it possible to grove the SiO_2 film not only on Si but also on the silicide film.

When tungsten silicide was used in place of molybdenum silicide,. the exposed surface of tungsten silicide could also be oxidized without oxidizing molybdenum and tungsten.

The same result could be obtained when silicides of molbdenum and tungsten were formed on single crystal silicon in place of polycrystalline silicon.

Example 9

Next, still another method of producing an MOS field effect semiconductor device in accordance with the present invention will be described with reference to Figure 6 which shows Example 3.

A 350 nm-thick tungsten film 1 was deposited on a 20 nm-thick gate SiO_2 film 2 that was formed on an Si crystal substrate 3. When etching the sample to a gate electrode pattern, there had been conventionally the problem that the SiO_2 film around the gate electrode was also damaged so that the SiO_2 film became thinner by about 10 nm and the breakdown voltage of the gate SiO_2 film got deteriorated. When the sample was heated at 900°C for 10 minutes in hydrogen containing 3% of water after etching the gate electrode of tungsten in accordance with the present invention, however, the damage of the SiO_2 film was recovered and at the same time, a fresh SiO_2 film grew. Accordingly, the breakdown voltage of the gate SiO_2 film was improved. This heat-treatment may be effected after etching and removing the SiO_2 film around the gate, and the same result could be obtained when the heat-treatment was effected without removing the SiO_2 film.

Example 10

The following two kinds of wafers were prepared. First, an Si wafer having formed a tungsten film on the surface thereof was heated in an oxygen atmosphere to form a 300 nm-thick tungsten oxide film. Separately, an Si wafer was washed by hydrofluoric acid to prepare a wafer (up to 2 nm thick) hardly having any oxide film. These two kinds of wafers were heated at 1,000°C for 1 hour in hydrogen containing 3% of water and their surfaces were analyzed by X-ray photoelectronic spectrometry. As a result, the tungsten oxide was reduced to tungsten due to the heat-treatment but the Si wafers were oxidized and an SiO_2 film was formed on the surface. The resulting SiO_2 film was found to be 58 nm thick as a result of measurement by an elipsometer.

As described above, silicon can be selectively oxidized without oxidizing tungsten and molybdenum during the fabrication of a semiconductor device by using H_2O/H_2 as the atmosphere of heat-treatment and by adjusting their partial pressure ratio. As a result, the so-called "light oxidation" process, that has been employed in the conventional polycrystalline silicon gate process, can be also used in the fabrication process of MOS transistors using tungsten or molybdenum for the gate. In other words,

the present invention eliminates the problem of oxidation of tungsten and molybdenum during fabrication of semiconductor devices and a process approximate to the one used in the conventional polycrystalline silicon process can now be used. Moreover, the characteristics of the resulting device can be remarkably stabilized in comparison with the tungsten or molybdenum gate process not using the H_2O/H_2 heat-treatment.

Example 11

In an Si gate process for fabricating an MOS transistor using a polycrystalline silicon film for a gate electrode, a so-called "glass flow" process is effected in which after the Si gate is covered with a PSG (phosphosilicate glass) which is an inter-layer insulating film, the surface of the PSG film is made smooth. When Mo or W is used for the gate, however, the oxidation of Mo or W due to oxygen will occur when heated in oxygen or nitrogen, even if Mo or W is covered with the PSG film because pin holes exist in the PSG film. When the sample was heated at 1,000°C for 30 minutes, for example, in the H_2+H_2O (5% moisture content) atmosphere in accordance with the present invention, however, the surface of the 500 nm-thick PSG film (P concentration = 12 mol%)

covering W was made sufficiently flat. Accordingly, the present invention made it possible to carry out "glass flow" without the possibility of oxidation of W or Mo.

As described above, the present invention makes it possible to selectively oxidize only Si and to form an SiO_2 film without oxidizing W or Mo and to remarkably improve the reliability and producibility of semiconductor devices using these materials. Particularly when W or Mo is used as the low resistance electrode of an MOS field effect semiconductor device, compatibility with the Si gate process can be improved. For instance, the "light oxidation" process becomes feasible. Since the present invention uses hydrogen containing water as the heating atmosphere, it can be easily practised using an ordinary heating apparatus consisting of a silica tube and an electric furnace and is excellent in both mass-producibility and economy.

CLAIMS:

1. A method of producing a semiconductor device including the step of selectively oxidizing silicon without substantially oxidizing tungsten and/or molybdenum by carrying out heat-treatment in a hydrogen atmosphere containing vapor.

2. The method of producing a semiconductor device as defined in claim 1 wherein said silicon is single crystal silicon, polycrystalline silicon or silicon contained in tungsten- or molybdenum silicides.

3. A method of producing a semiconductor device including the following steps:

(a) an insulating film (2) on a semiconductor substrate (3);

(b) forming a tungsten or molybdenum film (1) having a desired shape at a desired portion on said insulating film (2);

(c) doping an impurity having a conductivity type opposite to that of said semiconductor substrate (3) to the surface region of said semiconductor substrate using said tungsten or molybdenum film (1) as the mask;and

(d) carrying out heat-treatment in hydrogen gas

containing vapor so as to selectively oxidize the surface of said semiconductor substrate (3), where said tungsten or molybdenum film (1) is not deposited, without substantially oxidizing said tungsten or molybdenum film (1).

4. The method of producing a semiconductor device as defined in claim 3 wherein doping of said impurity is carried out by laminating a mask film (2') on said tungsten or molybdenum film (1) and then effecting ion implantation.

5. The method of producing a semiconductor device as defined in claim 4 wherein said mask film (2') consists of at least one member selected from the group consisting of a polycrystalline silicon film, a phosphosilicate glass film, an SiO_2 film and an Si_3N_4 film.

6. The method of producing a semiconductor device as defined in claim 3 wherein said insulating film (2) is an SiO_2 film.

7. The method of producing a semiconductor device as defined in claim 3 wherein said tungsten or molybdenum film (1) is the gate electrode of an MIS field effect semiconductor device.

8. A method of producing a semiconductor device including the following steps:

(a) forming an insulating film (2) on a semiconductor substrate (3);

(b) laminating a tungsten or molybdenum film (1) on said insulating film (2);

(c) removing a desired portion of said tungsten or molybdenum film (1) by etching; and

(d) carrying out heat-treatment in hydrogen gas containing vapor to oxidize the surface of said semiconductor substrate (3), where said tungsten or molybdenum film (1) is not deposited, without substantially oxidizing said tungsten or molybdenum film (1).

9. The method of producing a semiconductor device as defined in claim 3 or 8 wherein said heat-treatment is carried out after the exposed portion of said insulating film (2) is removed by etching.

10. The method of producing a semiconductor device as defined in claim 3 or 8 wherein said heat-treatment is carried out without removing said insulating film (2).

11. The method of producing a semiconductor device as defined in claim 2, 3 or 9 wherein the partial pressure ratio between said vapor and said hydrogen gas in said

heat-treatment and the heat-treating temperature are selected as the values falling in the range between the curve a and the curve c of Figure 1.

12. The method of producing a semiconductor device as defined in claim 11 wherein said heat treating temperature is from about 400°C to about 1,200°C.

FIG. 1

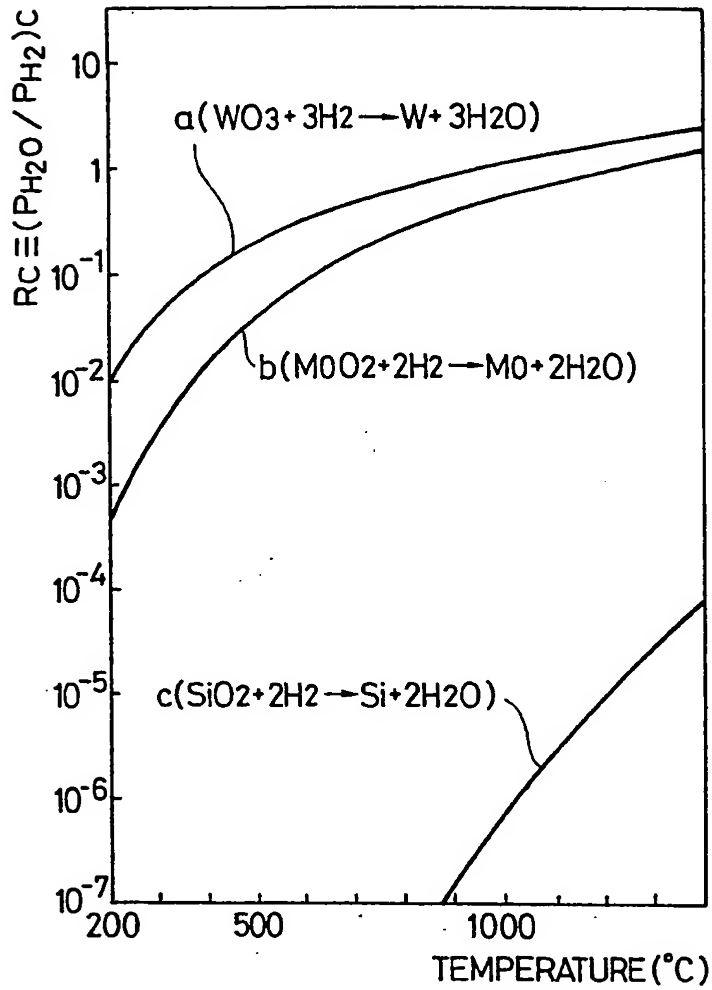

RC ≡ (P_{H_2O} / P_{H_2})C
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
a(WO3 + 3H2 → W + 3H2O)
b(MOO2 + 2H2 → MO + 2H2O)
c(SiO2 + 2H2 → Si + 2H2O)
200
500
1000
TEMPERATURE (°C)

FIG. 2

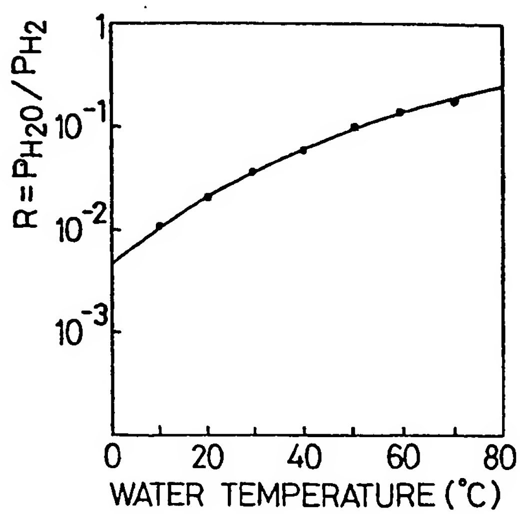

R = P_{H_2O} / P_{H_2}
1
10^{-1}
10^{-2}
10^{-3}
0
20
40
60
80
WATER TEMPERATURE (°C)

FIG. 3

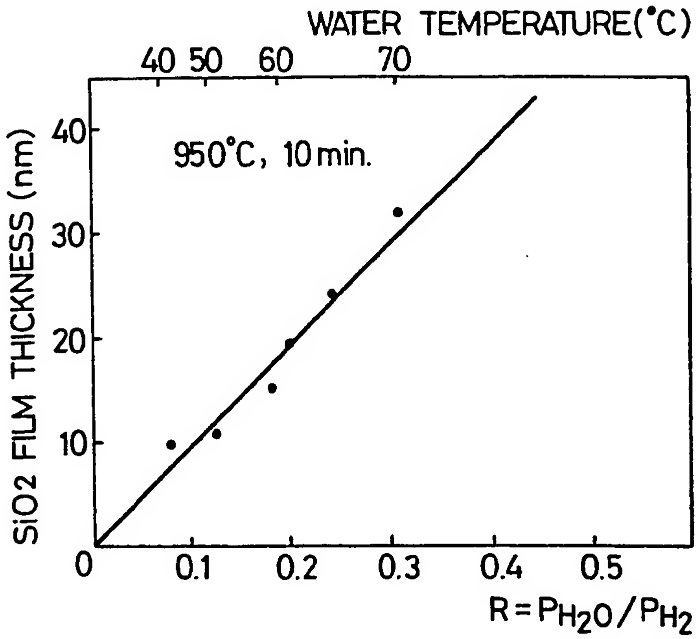

WATER TEMPERATURE(°C)
40 50 60 70
950°C, 10 min.
SiO2 FILM THICKNESS (nm)
40
30
20
10
0
0.1 0.2 0.3 0.4 0.5
R = P_{H_2O}/P_{H_2}

FIG 4

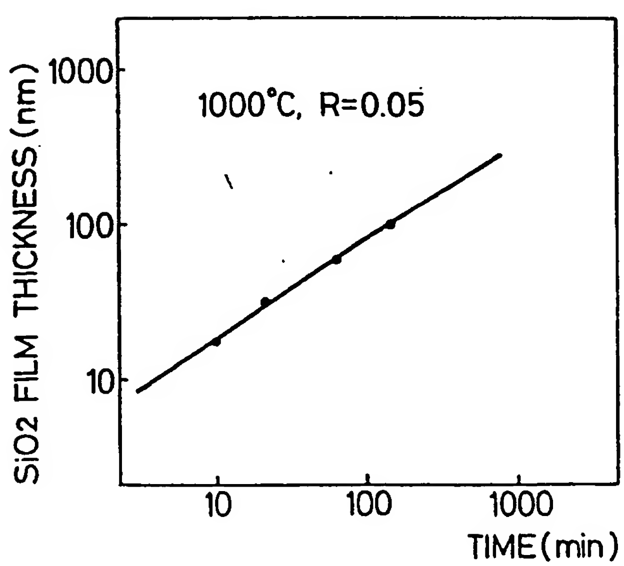

1000°C, R=0.05
SiO2 FILM THICKNESS (nm)
1000
100
10
10 100 1000
TIME (min)

FIG. 6a

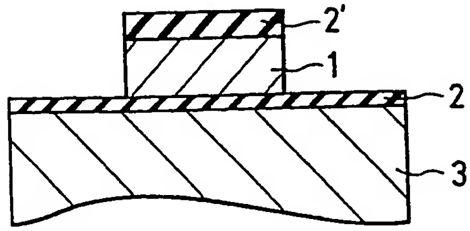


FIG. 6b

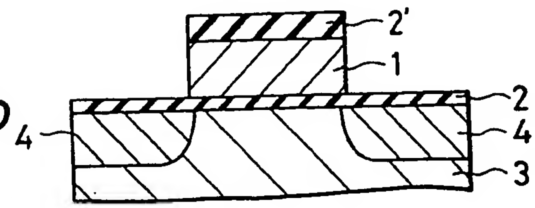


FIG. 6c

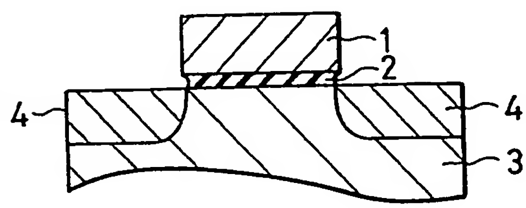


FIG. 6d

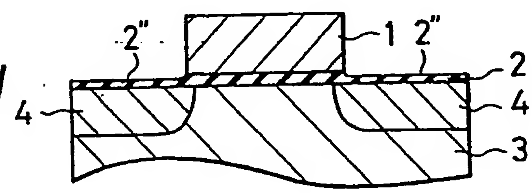


FIG. 6e

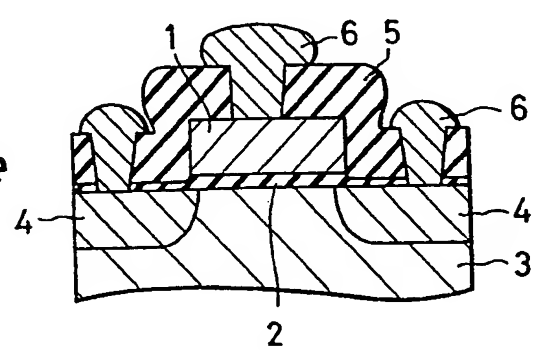


FIG. 5

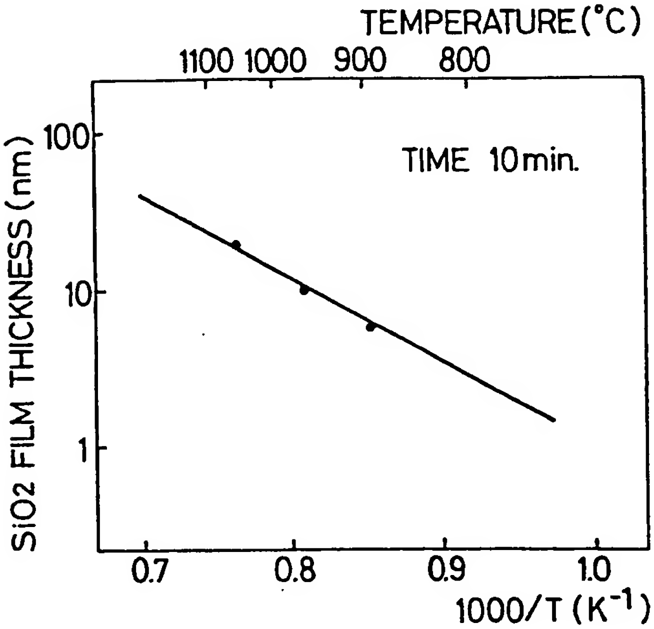


FIG. 7a

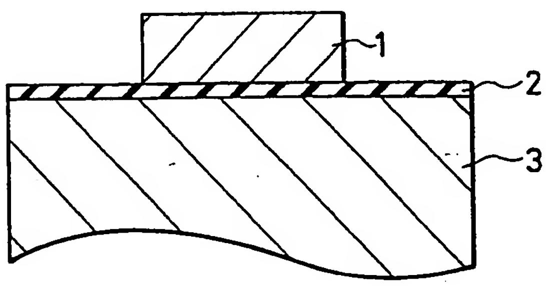


FIG. 7b

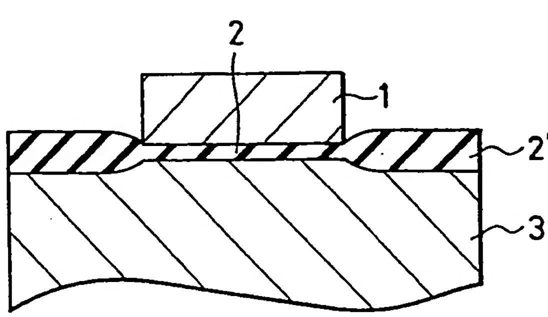


FIG. 8a

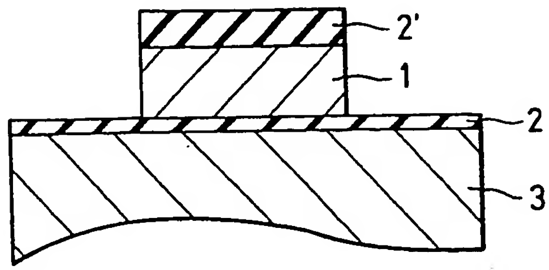


FIG. 8b

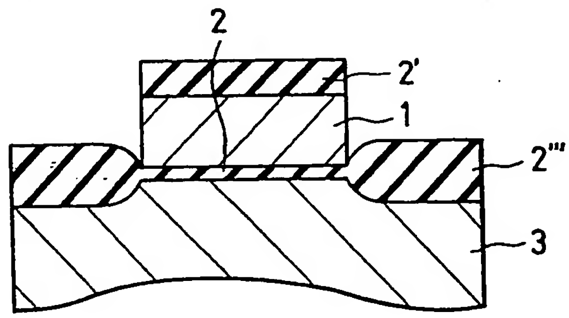


FIG. 9a

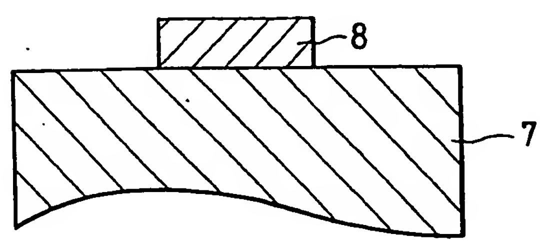


FIG. 9b

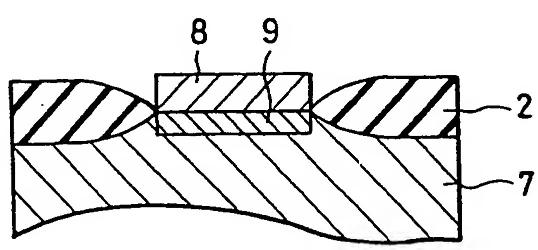


FIG. 10a

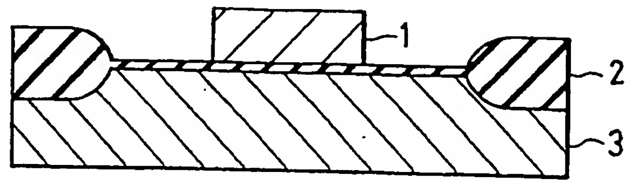


FIG. 10b

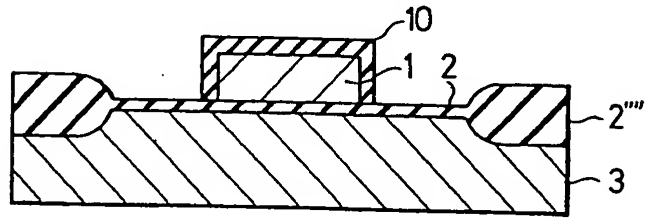


FIG. 10c

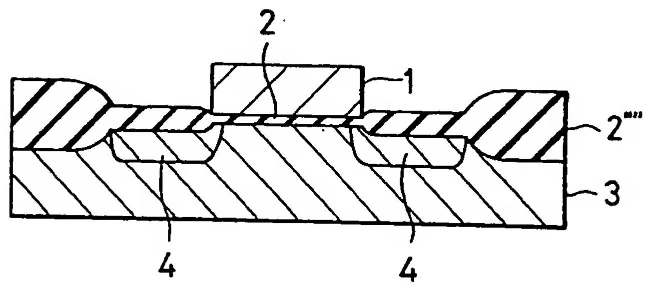


FIG. 11a

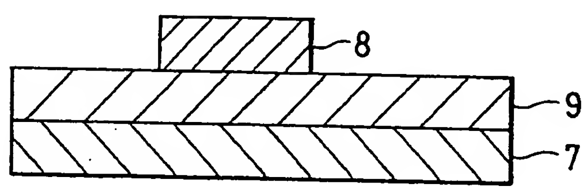
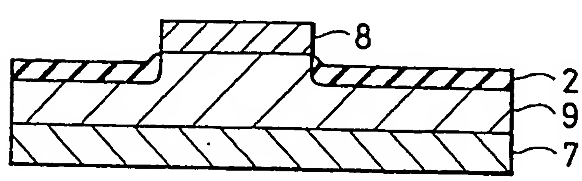


FIG. 11b



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